Strangeness production in jets from p+p $\sqrt{s} = 200$ GeV collisions

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Abstract.

Measurements of strangeness production in jets help illuminate the QCD mechanisms in fragmentation. Furthermore, they provide a crucial baseline for heavy-ion studies where modifications in jet chemistry have recently been predicted. We present new results on strange particle production in jets from p+p $\sqrt{s} = 200$ GeV collisions measured by the STAR experiment. The momentum distributions of the Λ , $\bar{\Lambda}$ and K_S^0 particles are obtained using various jet finding algorithms, and then compared to various models. Strange particle ratios in jets are obtained and compared to values obtained from the inclusive spectra. Finally, we show jets tagged with leading strange baryons and mesons, in order to investigate whether gluon or quark jets can be isolated in this way.

1. Introduction

We report measurements of strange particle momentum distributions in jets from p+p $\sqrt{s} = 200$ collisions measured by the STAR experiment. These results provide additional tests to QCD inspired models of fragmentation such as PYTHIA [1] or the Modified Leading Log Approximation (MLLA) [2, 3, 4, 5], beyond the usual comparisons to charged hadron momentum distributions. Furthermore, predictions for the modification of jet chemistry in heavy-ion collisions relative to p+p have been made [6]. These predictions show the K/π and p/π ratios in jets are expected to be higher in the presence of a medium. It is therefore essential we test theoretical descriptions of identified particle momentum distributions in p+p jets, if predictions in the modification of heavy-ion jet chemistry are to be made. Finally, since jets are from hard processes, comparisons of particles yields in jets to inclusive spectrum measurements may help elucidate the contributions from hard processes to those measurements as a function of p_T.

2. Analysis

The data presented are from $\sim$ 8 million jet-patch triggered p+p $\sqrt{s_{NN}} = 200$ GeV events recorded in 2006 by the STAR experiment. The jet-patch trigger is designed to select events with jets, and thus requires energies above 8 GeV to be deposited in an area $\Delta\eta \times \Delta\phi = 1 \times 1$ within the electromagnetic calorimeter [7]. The Time Projection Chamber (TPC) is used to detect the charged particles [8], while the barrel electromagnetic calorimeter, BEMC, is used for neutral particles. Three jet finders are employed from the fast-jet package [9]: k_t, anti-k_t and SIS. We select recoil jets with respect to the triggered jets to measure fragmentation functions.

This is because the triggered jets have a bias towards the neutral jet component. The jets are found within a resolution parameter, R = 0.4 and a jet axis η cut < 0.6 to ensure the jet area lies within the TPC/BEMC acceptance. The resolution parameter can be thought of as an effective jet radius in the η, ϕ plane. The minimum p_T cut for a charged particle is 200 MeV/c, while the minimum calorimeter tower energy is 200 MeV. Towers which match charged particles are removed from the jet to avoid over counting of electrons and Minimum Ionising Particles (MIPs). No corrections are applied to the jet energy scale which means the reconstructed jet p_T is likely to be less than the actual jet p_T due to TPC/BEMC detection inefficiencies, and missing neutral energy principally from undetected n and K_L^0 particles. Studies are underway to determine a correction for this. Finally, in order to measure the momentum distributions of the Λ, $\bar{\Lambda}$, and K_S^0 particles, V0s are identified within the jet area from TPC tracks. The invariant mass distributions are calculated to extract the yields of these particles via their dominant decay channels: $\Lambda \rightarrow p + \pi^-$, $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$, $K_S^0 \rightarrow \pi^+ + \pi^-$. In conjunction with a minimum p_T cut of 1 GeV/c, a series of topological cuts are placed on the V0s to minimise the relative background contribution, and ensure the signal to background ratios are approximately the same for each particle. The residual background after all cuts is not yet removed from the fragment yields.

3. Results

Strange particle momentum distributions as a function of the reconstructed jet p_T are shown in figure 1. The momentum distribution is expressed in $\xi = log(jp_T/fp_T)$, where jp_T and fp_T are the reconstructed jet and fragment p_T respectively. For a particular particle species, the integral of the ξ function gives its mean multiplicity per jet. The uncertainties are statistical added in quadrature to the small differences obtained by comparing the three different jet finders. A data point is the mid point value between the lowest and highest values the three jet finders give.
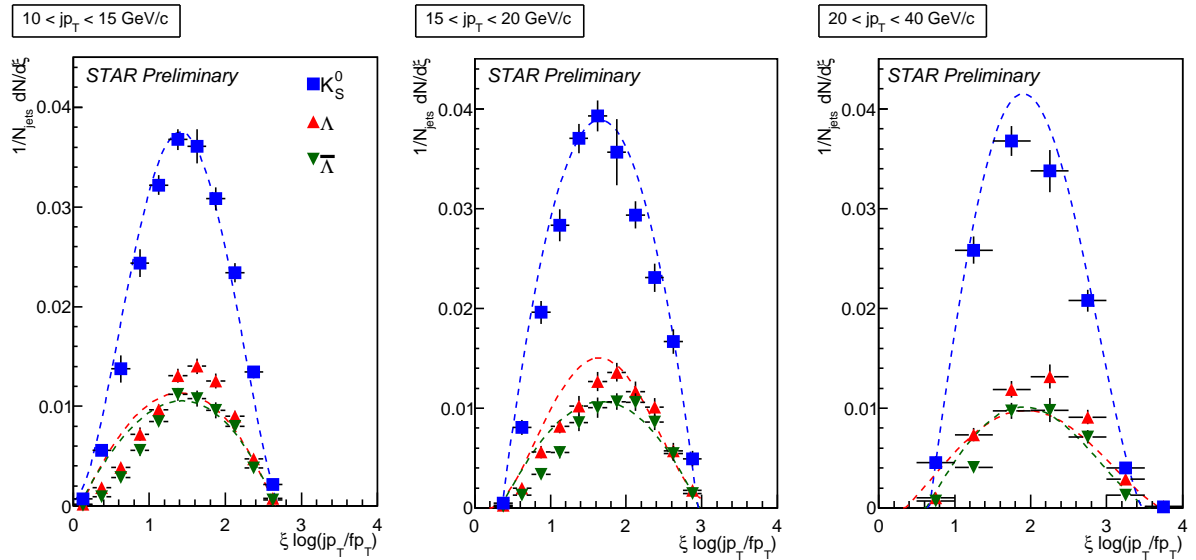

Figure 1. Data points show strange particle momentum distributions for three reconstructed jet p_T ranges in p+p $\sqrt{s_{NN}} = 200$ GeV collisions. The strange particle yields are not corrected for tracking efficiency. The symbols jp_T and fp_T are the reconstructed jet and fragment p_T respectively. The curves show polynomial fits to PYTHIA 6.4 predictions. These predictions are obtained from PYTHIA events ran through the STAR detector simulator. The same applies to all other figures.

The measured V0 yields are not yet corrected for acceptance and TPC tracking inefficiencies. The PYTHIA predictions are obtained by processing PYTHIA events with STAR's detector simulation, and running the track, jet, and V0 reconstruction software on the simulated output in the same way as the real data. This ensures the PYTHIA events are subject to the same acceptance restrictions/detector inefficiencies as the real data. All PYTHIA predictions shown in these proceedings are from version 6.4 with Tune A. We find that PYTHIA gives a reasonable description of the K_S^0 data. JETSET (the jet production scheme in PYTHIA) has also been shown to describe $K^{\pm}$ fragmentation functions in $e^+ + e^-$ collisions well, where the jet energies range $5 < E_{jet} < 46$ GeV [10]. Furthermore, PYTHIA has been shown to describe charged hadron momentum distributions in p+p collisions at the same center of mass energy [11]. On the other hand, we note that the PYTHIA description of Λ and $\bar{\Lambda}$ momentum distributions are less satisfactory. Although the predictions appear to predict the correct yield over all ξ, they tend to over predict the yields at low ξ and under predict the yields at intermediate ξ. Whether this is due to a mismatch in the reconstruction of PYTHIA events and real data, or due to physics, is under investigation.
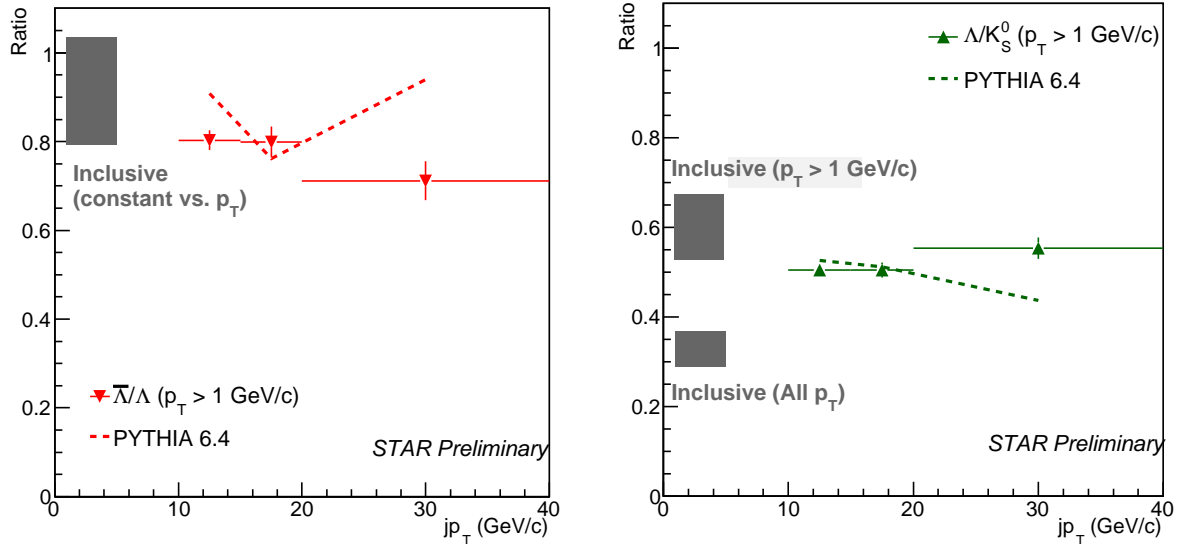

Figure 2. $\bar{\Lambda}/\Lambda$ and Λ/K_S^0 ratios in jets for three reconstructed jet p_T ranges in p+p $\sqrt{s_{NN}} = 200$ GeV collisions. In each case, the minimum particle p_T is 1 GeV/c and ratios are corrected for TPC efficiency and acceptance. The uncertainties are statistical added in quadrature to the small differences obtained by comparing the three different jet finders. Inclusive refers to values obtained from inclusive spectra measurements [12]. The vertical size of shaded boxes reflects statistical and systematic uncertainties added in quadrature.

In figure 2, we show ratios of integrated yields $\bar{\Lambda}/\Lambda$ and Λ/K_S^0 for $p_T > 1$ GeV/c as a function of reconstructed jet p_T. The analysis shows the $\bar{\Lambda}/\Lambda$ ratio is below 1 showing the baryon asymmetry in the colliding system (p+p) is transferred to jets over all jet energies measured. We also find the $\bar{\Lambda}/\Lambda$ ratio is consistent with the value obtained from inclusive spectra measurements [12]. PYTHIA also seems to reproduce the magnitude of the ratio. The jaggedness of the predictions is due statistical fluctuations which are $\sim 10\%$ and not shown. Regarding the Λ/K_S^0 ratios in jets, these are higher than values from inclusive spectrum measurements over all p_T. The inclusive spectrum measurement will be dominated by production below 1 GeV/c. When we compare the ratios in jets to the inclusive spectrum measurement above 1 GeV/c, we find

they are generally consistent. This may mean that Λ and K_S^0 spectrum measurements with $p_T > 1$ GeV/c have a dominant contribution from hard processes i.e. jet production. However, measurements of the same ratio from the underlying event are needed to further qualify this observation. We also find PYTHIA again reproduces the magnitude of the ratio.
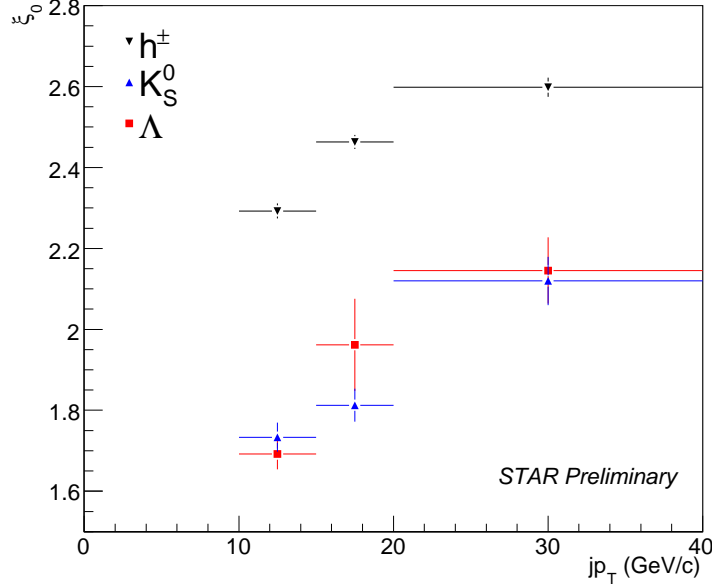

Figure 3. Peak position of ξ (ξ_0) for charged hadrons, Λ and K_S^0 particles for three reconstructed jet p_T ranges in p+p $\sqrt{s_{NN}} = 200$ GeV collisions. The uncertainties are statistical added in quadrature to the small differences obtained by comparing the three different jet finders.

In figure 3, we show the position of the maximum of the ξ distribution, ξ_0, for the various particles as a function of the reconstructed jet p_T. Since the p_T dependent tracking inefficiency/acceptance will distort the shape of the ξ distribution, we correct the distributions using embedding which determines the V0 reconstruction efficiency. A Gaussian is fitted in the peak region to extract ξ_0. The fit range is chosen to avoid the region in ξ affected by the minimum p_T cut on the fragments. In the MLLA scheme, the position of the maximum can be described by the following relation [5];

$$\xi_0 = Y + \sqrt{cY} - c \qquad (1)$$

where c is a constant and Y is:

$$Y = log\left(\frac{E_{jet}sin(\theta_0)}{Q_0}\right) \qquad (2)$$

where θ_0 is the jet opening angle, and Q_0 is the effective transverse momentum (relative to the jet axis) where a parton ceases to branch in the parton shower. MLLA predictions for momentum distributions of hadrons with mass M_0 typically assume $Q_0 \simeq M_0$ [6]. Equation 2 then implies a scaling behaviour of ξ_0 with the mass of the hadron i.e. ξ_0 should decrease for the higher mass hadrons. The value of ξ_0 should also increase with jet energy for a given hadron which is observed in figure 3 for all particles. However, we find that $\xi_0(K_S^0) \sim \xi_0(\Lambda)$ which is contrary to the expected scaling. On the other hand, $\xi_0(h^\pm) > \xi_0(K_S^0)$ and $\xi_0(\Lambda)$ which is consistent with such a scaling assuming pions dominate particle production in jets.

A similar observation was made for π, K, p fragmentation functions for similar jet energies in $e^+ + e^-$ collisions [13]. Finally, we note in interest that if we extract the mode of the transverse rapidity, y_T, distribution (motivated by this study [14]), we find a mass scaling in y_T space i.e $y_{T,0}(h^\pm) > y_{T,0}(K_S^0)) > y_{T,0}(\Lambda)$ for a given reconstructed jet p_T bin. For a given particle species, we also find $y_{T,0}$ increases with jet energy.
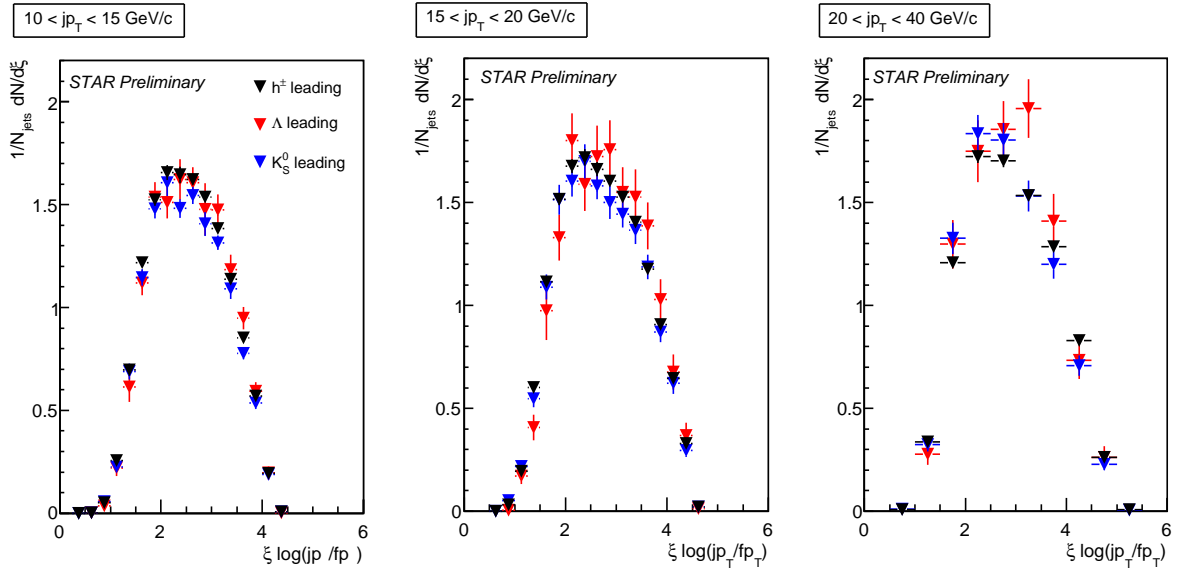

Figure 4. Momentum distributions of non-leading charged hadrons for three reconstructed jet p_T ranges in p+p $\sqrt{s_{NN}} = 200$ GeV collisions. The black points show data for jets where the leading particle is a charged hadron, red corresponds to jets with leading Λ particles, and the blue points correspond to jets with leading K_S^0 particles. The charged hadron yields are not corrected for tracking efficiency. jp_T and fp_T are the reconstructed jet and fragment p_T respectively. The uncertainties are statistical added in quadrature to the small differences obtained by comparing the three different jet finders.

In figure 4 we show the momentum distributions of *non-leading* charged hadrons for the cases where the leading particle is a charged hadron, Λ, or K_S^0. We want to investigate whether tagging jets according to the species of the leading hadron, preferentially selects on gluon or quark jets. Both measured data [15] and theoretical predictions show hadron multiplicities are larger in gluon jets compared to quark jets: MLLA gives the ratio 9/4 for gluon/quark jet multiplicities. Thus, if tagging jets with particle A preferentially selected gluon jets, and tagging jets with particle B preferentially selected quark jets, we would expect the jets associated with particle A to have more non-leading charged hadrons compared to jets associated with particle B. However, in figure 4 we observe at given jet energy, the charged hadron multiplicities are the same for each of the tagged jets. This might be expected for the highest jet p_T bin where jet production is expected to be dominated by hard scattering of valance quarks, however at lower jet energies there should be mixture of quark and gluon jets [16]. Therefore, our observation suggests quark/gluon jets cannot be tagged in this way. Further studies are underway to confirm this.

4. Summary
In summary, we have shown measurements of strange particle momentum distributions. We have found that PYTHIA describes the K_S^0 momentum distributions well, however we observe

some deviations for the Λ and $\bar{\Lambda}$ data. We have found that $\bar{\Lambda}/\Lambda$ ratios ($p_T > 1$ GeV/c) in jets are consistent with values obtained from inclusive spectra. Λ/K^0_S ratios ($p_T > 1$ GeV/c) in jets were found to be similar to values obtained from inclusive spectra in the same p_T range. This may suggest that Λ and K^0_S production above 1 GeV/c is dominated by hard processes in p+p $\sqrt{s_{NN}} = 200$ GeV collisions. We investigated a mass scaling of the peak position of ξ (inferred from MLLA), and found although $\xi_0(h^{\pm}) > \xi_0(K^0_S)$ and $\xi_0(\Lambda)$, $\xi_0(K^0_S) \sim \xi_0(\Lambda)$. Finally, we have found tagging jets with leading strange baryons/mesons may not preferentially select on quark/gluon jets.

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